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Windbreak Plant Species for Odor Management around Poultry Production Facilities

Introduction

The U.S. poultry industry is the world's largest producer and second largest exporter of poultry meat. U.S. consumption of poultry meat (broilers, other chicken, and turkey) is considerably higher than beef or pork. Considering overall animal production in the U.S., the total number of chickens per farm has increased considerably. This national trend of producing more chickens on fewer farms is especially evident in the Mid-Atlantic. From 1982 to 2002, while the number of broiler chicken farms decreased by 11 percent, the number of birds produced increased by 54 percent in Delaware, Maryland and Virginia (National Agricultural Statistical Service). While poultry producers are increasing the efficiency of their operations, Mid-Atlantic States have been losing farmland, in most cases to development. From 1997 to 2002, Maryland, Delaware and Virginia, on average, have lost 5 percent of their state's farmland. This loss of farmland totals almost 300,000 acres (National Agriculture Statistics Service). This trend of farmland loss is at a rate almost four times that of the nation as a whole. The encroachment of houses on farmland in the Mid-Atlantic, combined with the trend toward more concentrated poultry operations, points to a much greater need for vegetative buffers.

A windbreak will significantly improve the visual appearance of the farm and foster good neighbor relations. Photo by George Malone.

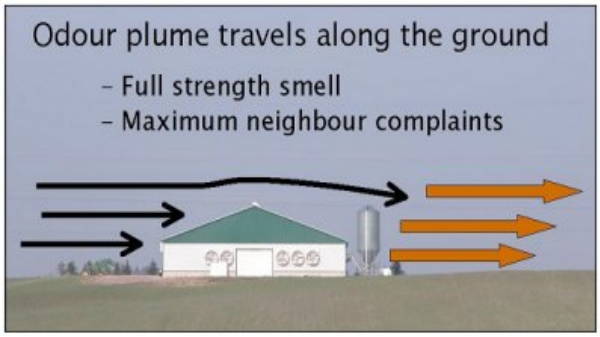
Benefits of Windbreaks/Buffers

Handling of Odor and Dust Particles

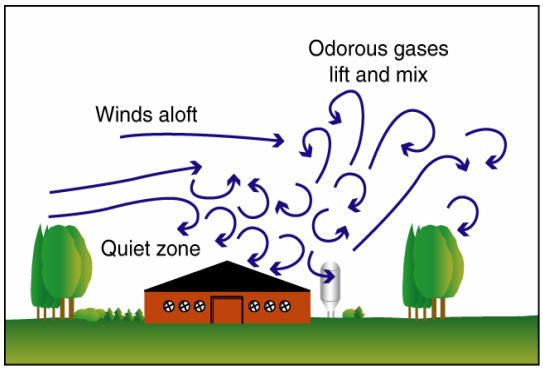
Tree and shrub buffers absorb gaseous ammonia, precipitate out dust by slowing the air speed from exhaust fans, and deflect the odor plume into the atmosphere above the buffer, all in a very cost-effective way. With odor management, the buffer becomes part of the overall management

of the farm operation. Odor from poultry houses typically travels downwind, along the ground, in a concentrated plume. By planting trees and shrubs around poultry houses farmers can disrupt the plume and mix it with the prevailing winds to dilute odor.

Ammonia is the gas of greatest concern to the poultry industry. Plants have the ability to absorb aerial ammonia (Yin et al., 1998). This translates into higher growth rates, as plants located in front of exhaust fans were found to have higher amounts of nitrogen and dry matter weights compared to control plants (Patterson 2005). Plant growth is increased with the right amount of ammonia; however, there is a critical threshold where too much ammonia will cause tissue necrosis, reduced growth, and greater frost sensitivity (Van deer Eerden et al 1998). During the summer, trees reduced air velocity by 99%, dust by 49% and ammonia by 46% downwind of the trees (Malone 2006). The direction of the wind strongly influenced these results; wind blowing toward the fans "increased" the efficacy of the buffer while wind blowing in the opposite direction "decreased" this efficacy (Malone 2006).



Without windbreaks and without wind management the odor plumes are picked up by passing air masses and travel near the ground with little or no dilution or filtration. Diagram by Todd Leuty.



Windbreaks located upwind and downwind of poultry farms will reduce and manipulate air flow around the facility to reduce the spread of odors. Overhead winds can lift particles and gases into the lower atmosphere to help dilute and disperse odors. Also, more clean air diverts up and over the source of odor. Diagram by Todd Leuty.

Visual and Noise Barriers

The primary benefit from plant buffers installed near the poultry production facility is the improved visual perception of the facility, but they also can reduce noise by up to 50%. This is extremely important to good neighbor relations where residential housing exists near poultry farms. These benefits are especially important in the mid-Atlantic, with its booming housing market.

This photo shows the problem and the solution. Housing is increasingly encroaching on typically agricultural lands. The Austree hybid willow plants and Norway spruces will absorb gaseous ammonia and odors, and hide the poultry operations from their neighbors. Photo by PA NRCS.

Other Benefits

Windbreaks/buffers may also reduce the spread of specific infectious diseases in poultry operations by blocking, intercepting or diverting wind-borne infectious organisms away from buildings. However, use care to

select windbreak plants that do not produce large amounts of seed or fruits that attract birds which may spread these diseases. Fruiting can be avoided by using male cultivars of dioecious plants (e.g., hollies) or fruitless cultivars.

Windbreaks help filter and capture nutrients from runoff and ground water through root absorption of up to an estimated 80% of the nitrogen and phosphorus in certain environments. Nutrient uptake by plants helps reduce the amount of nutrients that are available to enter adjacent water courses.

Windbreak/Buffer Design and Maintenance

Plant selection will vary depending on the site. Select plants based on the following factors:

- mature height and spread of the plant
- soil type
- drainage and moisture conditions
- wind conditions
- precipitation
- USDA hardiness range
- growth rate
- whether it is a native or introduced species
- location and distance from exhaust fans
- farm layout (location of roads and neighbors)

To maximize particulate trapping, select plants based on the following factors:

- high leaf surface roughness (plants with leaf hairs, leaf veins, and small leaf size)
- complex leaf shapes
- large leaf areas
- medium to rapid plant growth rates

Windbreak Design

Selection and Arrangement

It is usually best to select several different species of trees and shrubs for use in windbreaks. This helps prevent the loss or destruction of the entire windbreak if insect pests or tree diseases occur on certain species. Having diversity also offers a better chance for tree survival during alternating seasons of drought and/or wet soil conditions.

Deciduous shrubs are generally planted in the perimeter rows, followed by deciduous trees towards the middle or along the downwind side where they can grow more efficiently. Deciduous plants planted near the tunnel ventilation fans will accumulate dust particles during the growing season when the fans are operating. Those leaves will then drop off in the autumn when the fans are not being used. The plants will then leaf out in the spring repeating this process.

To provide an effective windbreak, a combination of plant growth rates should be used in the overall design. Within each row, select species with similar growth rates to provide an even

height. Faster growing plants, which provide quick visual screening, generally are short lived and will need to be replaced sooner than slower growing species.

Where site conditions allow, place plantings around the entire perimeter of the odor source. A curved planting is easier to cultivate and offers a more pleasing appearance than one with squared corners. The closer the windbreak is positioned to the poultry house, the better the odor, dust and ammonia will be trapped and dispersed (Lin et al 2006). However, the windbreak should be placed a minimum of 50 feet from the sidewalls and 80 feet from the ends of the houses for access. Any closer to the ventilation fans will cause the plants to become desiccated from the higher wind speed. The nearest row of windbreak plantings should be set back from buildings and waste storage areas by a distance that is at least 10 times the exhaust fan diameter. For example, if the tunnel ventilation fan has a diameter of 6 feet, then the first line of plants should be planted 60 feet away. In those cases where multiple fans are used in one location, this planting distance formula will need to be modified. Consider mounding the soil to create berms with plants located on top of the mound. When using evergreen plants, consider that winter snows will be heavily deposited down wind at a distance of 10 times the total height of the plants. Be sure that roads or other buildings are not located in this area where additional snow will be deposited.

The exhaust of this multiple fan poultry house is effectively deflected by the berm and plants. Due to the quantity of fans the distance between plants and exhaust fans is much more than usual, 150 feet shown here. Irrigation is important for plants in this situation as the soil dries much more quickly due to the slope. Photo by PA NRCS.

Evergreens

Evergreens are useful for providing year-round visual screening and particulate trapping, but tend to become overloaded with particulates if planted too close to ventilation fans. Poultry house particulates do not wash off easily and thick coatings of particulates on evergreens will result in early mortality. Best results will be achieved when evergreens are placed on the downwind side of deciduous trees, which will intercept significant amounts of particulates during the growing season. The exception to this rule is for evergreen hollies (*Ilex sp.*) which have a thick waxy leaf surface which will tolerate the thick coatings of particulates which will be washed off by the rain. This characteristic allows evergreen hollies to be used in the high particulate load areas directly behind ventilation fans. White and loblolly pines have been used extensively in the mid-Atlantic as windbreaks. These plants have been used with poor results and are not tolerant of high levels of ammonia. They are not recommended for planting in areas opposite ventilation fans, but may be an option for use in non-discharge areas.

Number of Rows

The proper number of rows in a windbreak will depend on the space available, and the species to be used. When possible, windbreaks should consist of three or more rows of deciduous and evergreen species of plants. Additional rows of plants may be needed near the tunnel ventilation fans as those plants will be growing in a more stressful environment and plant death will be more

frequent. Selecting the correct species for the situation, and then following up with proper care is much more important than the number or rows.

Spacing Within the Row

The spacing between the plants within the row will vary depending on the size and growth rate of the plants. Faster growing plants should be placed further apart than slower growing plants. Overall, spacing within the windbreak should be closer than the spacing typically used for landscape plantings. This will promote quicker vertical growth which will shade out weed competition and decrease the amount of time that it takes for the windbreak to become functional. Greater crown and root spread can be expected from hardwoods than from evergreens. General guidelines are as follows:

Small Shrubs (4 feet – 12 feet tall) – 4 feet to 6 feet apart
Large Shrubs and Small Trees (12 feet – 30 feet tall) – 6 feet to 10 feet apart
Large Trees (over 30 feet tall) – 10 feet to 14 feet apart
Evergreen Trees – 8 feet to 14 feet apart depending on the species

Spacing Between Rows

Spacing between rows depends on the amount of moisture available, the species planted in each row, and the width of implements used for cultivation or maintenance. Planting rows too closely together is a common mistake. After a few years of growth, severe competition for moisture and nutrients begins and faster-growing trees overtop others. Machinery often cannot move between the rows, the windbreak falls into disrepair and eventually becomes ineffective. In most cases, a spacing of 16 to 20 feet between rows is recommended depending on site conditions and species selected. If the site is dry, more space is necessary to minimize competition. More space would also be needed for species which are sensitive to shade. The distance between the shrub row and the tree row does not need to be as great as the spacing between tree rows. Adequate spacing between deciduous and evergreen rows in necessary because faster growing deciduous trees tend to overtop and suppress evergreens if planted too close. Evergreen and deciduous trees should not be mixed in the same row for this same reason.

Windbreak Establishment and Maintenance

Stock Size

The best size of the planting stock will vary with the growth rate of the plant. Fast growing plants can be purchased small as their fast growth rate will quickly make up for their initial size. Conversely, slower growing plants should be purchased as large as possible since it will take longer for them to become a functional part of the windbreak. Bare-rooted seedlings are discouraged from being used due to their slower establishment time, and will suffer more from transplant shock, especially in this stressful environment. Either container or balled-and-burlapped plant material, which are more expensive than bare-rooted stock, are fine for use in poultry windbreaks.

Planting Time

The timing of planting varies with the type of plant (evergreen or deciduous). Evergreen plants are best planted in the early spring so that they have the entire growing season to grow new roots. This is important due to the fact that evergreens retain their leaves and are prone to drying

out in the winter when the soil is frozen and water is not available for uptake. Deciduous plants, on the other hand, can be planted either in the spring or autumn. Even after newly planted deciduous plants have dropped their leaves in the autumn, root growth is still taking place. Soil temperatures change less rapidly than air temperatures; therefore, soil usually retains warmth well into late autumn. During this time, watering is still very important during periods of little or no rain. The rule of thumb is to water anytime during the growing season when there is not 1 inch of rain within a week. Although not recommended, should bare-root deciduous plants be used, they must always be planted in early spring.

Moisture

Irrigation is very important during the first five years of plant establishment. Plant survival and the overall health of the plants will benefit from using drip irrigation. Either an emitter placed in the area of the plant or tubing with regularly spaced holes will work. Irrigation is especially important for those plants located in front of the fans, due to additional stresses from the desiccating high winds, ammonia and dust.

Weed Control

Weed control is also extremely important to the establishment and longevity of the windbreak. By using plastic weed barrier with organic mulch, competition from weeds will be limited, retaining soil moisture, and maximizing plant growth. Pre- and post-emergent herbicides may need to be used where the weed pressure is high. Follow all label directions and state pesticide guidelines. Weed management (especially grass control) is extremely important until the young plants have outgrown the weeds.

Replanting

Windbreaks plantings are seldom 100% successful. Prompt replacement of plants which do not survive is essential for the development of a functional poultry windbreak. Replacement planting should be continued for up to 3 years after the initial planting when conditions are again optimal for planting. It is very important to replant within the rows because the effectiveness of the windbreak depends largely on having full rows. It is a good idea to order a few extra plants when purchasing the plants and “heel them in” at a location where you can give them extra care. When replacements are needed you will have the same species, at the same age and size as the originals in the row. To “heel in” plants, remove the containers or plant directly the balled-and-burlapped stock at a very close spacing. Cover the roots with soil and water. If possible, heel in plants in a cool, shady place and water as needed.

Table 1. Proven Plants for Windbreaks/Buffers on Poultry Production Farms

The following table represents plants which have been planted as buffers around poultry farms in the Mid-Atlantic U.S. and have proven to be effective in passive ammonia absorption. Refer to the Appendix for information on Hardiness Zones.

Botanical Name/Cultivar	Common Name	Family	Hard. Zone[1]	Size (H x W)	Growth Rate*	Native Range
Gleditsia triacanthos var. *inermis*	honeylocust	Fabaceae	4 - 9	50' x 50'	fast	PA to MS, west to NE and TX
Ilex cornuta x *aquifolium* 'Nellie Stevens'	Nellie Stevens holly	Aquifoliceae	6 - 9	20' x 15'	fast	Asia, Europe
Ilex crenata 'Steeds'	Japanese holly	Aquifoliceae	6 - 9	8' x 4'	moderate	Japan, Korea, China
Ilex opaca	American holly	Aquifoliceae	5 - 9	40' x 20'	slow to moderate	MA to FL, west to MO and TX
Juniperus virginiana	eastern red cedar	Cupressaceae	3b - 9	40' x 20'	moderate	ME to FL, west to ND, CO and TX
Picea abies	Norway spruce	Pinaceae	3b - 7	50' x 25'	moderate to fast	north-central Europe
Populus deltoides x *nigra* 'Spike'	hybrid poplar	Salicaceae	4 - 7	70' x 30'	fast	sterile hybrid
Salix matsudana x *alba*	Austree hybrid willow	Salicaceae	4 - 8	60' x 15'	very fast	American/Asian hybrid (male)
Salix purpurea 'Streamco'	purpleosier willow	Salicaceae	4 - 7	15' x 15'	fast	Europe
Taxodium distichum	bald cypress	Taxodiaceae	5 - 9	70' x 20'	slow to moderate	DE to FL, west to MO and LA
Thuja plicata x *standishii* 'Green Giant'	arborvitae	Cupressaceae	5 - 7	60' x 20'	fast	hybrid
x*Cupressocyparis leylandii*	Leyland cypress	Cupressaceae	6 - 10	100' x 20'	very fast	hybrid

* Growth rates – slow = less than 1'/year, moderate = 1' – 2'/year, fast = 2' - 3'/year, very fast = over 3'/year

Table 2. Cultural Requirements of Proven Plants for Windbreaks/Buffers on Poultry Production Farms

For best results, always chose a plant species that meets your site conditions. Refer to the Appendix for information on Natural Drainage Classes.

Botanical Name/Cultivar	Common Name	Natural Drainage Class[2]					Light Requirements			Notes
		Excessively Drained	Well Drained	Moderate Well Drained	Somewhat Poorly Drained	Poorly Drained	Sun	Part Shade	Shade	
Gleditsia triacanthos var. *inermis*	honeylocust		X	X	X		X	X		Resistant to compacted soil, salt tolerant.
Ilex cornuta x *aquifolium* 'Nellie Stevens'	Nellie Stevens holly		X	X	X		X	X		Fruitless without a male pollinator.
Ilex crenata 'Steeds'	Japanese holly			X			X	X		Excellent for high emission load areas.
Ilex opaca	American holly	X X		X			X	X		Consider using 'Jersey Knight', a male fruitless cultivar.
Juniperus virginiana	eastern red cedar	X	X	X			X	X		Sensitive to soil compaction, salt tolerant.
Picea abies	Norway spruce				X		X			
Populus deltoides x *nigra* 'Spike'	hybrid poplar		X	X	X		X	X		
Salix matsudana x *alba*	Austree hybrid willow		X	X	X	X	X	X		Provides a visual screen within 1-2 years due to fast growth rate.

Botanical Name/Cultivar	Common Name	Natural Drainage Class[2]					Light Requirements			Notes
		Excessively Drained	Well Drained	Moderate Well Drained	Somewhat Poorly Drained	Poorly Drained	Sun	Part Shade	Shade	
Taxodium distichum	bald cypress		X	X	X	X	X			
Thuja plicata x *standishii* 'Green Giant'	arborvitae		X	X			X	X		
x*Cupressocyparis leylandii*	Leyland cypress	X		X			X	X		Fungal canker and insects can be a problem; 'Green Giant' arborvitae is the preferred alternative.

Table 3. Potential Plants for Windbreaks/Buffers of Poultry Production Farms

This table represents plants which have been planted as street trees and shrubs. In urban environments, tolerance to pollutants such as ozone and sulfur dioxide, salt, heat, drought, and soil compaction are necessary. While these plants have not yet been tested for use around poultry facilities, they should be considered for use and further evaluation given their tolerance of inhospitable environments. White and loblolly pines have been used with very poor results and are not tolerant of high levels of ammonia. Therefore, pines are not recommended for planting in areas opposite ventilation fans, but may be an option for use in non-discharge areas. Refer to the Appendix for information on Hardiness Zones.

Botanical Name	Common Name	Family	Cultivar	Hardiness Zone[1]	Size (H x W)	Growth Rate*	Native Range
Acer buergerianum	trident maple	Aceraceae		5 - 8	20' x 30'	slow-mod.	China
Acer campestre	hedge maple	Aceraceae	Queen Elizabeth	5 - 8	25' x 35'	slow	Europe
Acer negundo	boxelder	Aceraceae	Baron	3 - 9	30' x 50'	fast	entire US
Acer rubrum	red maple	Aceraceae	Brandywine	4 - 8	12' x 25'	moderate to fast	Eastern US
Acer rubrum x *saccharinum*	Freeman maple	Aceraceae	Autumn Blaze	4 - 8	40' x 50'	fast	Eastern US
Acer truncatum hybrid	purpleblow maple	Aceraceae	Norwegian Sunset, Pacific Sunset	4 - 8	25' x 35'	slow	Northern China, Russia
Alnus rugosa	speckled alder	Betulaceae		3 - 6	15' x 20'	moderate	Canada south to IL and VA
Alnus serrulata	hazel alder	Betulaceae		5 - 9	15' x 15'	moderate	ME to FL, west to KS and LA
Amorpha fruticosa	false indigo	Fabaceae		4 - 9	10' x 15'	moderate	CT to FL, west to MN and LA
Caragana arborescens	Siberian pea shrub	Fabaceae		2 - 7	15' x 15'	moderate to fast	Siberia and Mongolia
Celtis laevigata	sugar hackberry	Celastraceae	All Seasons, Magnifica	4 - 8	25' x 40'	moderate to fast	VA to FL, west to MO and TX

Botanical Name	Common Name	Family	Cultivar	Hardiness Zone[1]	Size (H x W)	Growth Rate*	Native Range
Celtis occidentalis	common hackberry	Celastraceae		3 - 9	50' x 50'	moderate to fast	MA to NC, west to ND and OK
Cercis canadensis	redbud	Fabaceae		3 - 9	25' x 25'	moderate	NJ to FL, west to IA and TX
Ginkgo biloba	ginkgo	Ginkgoaceae	Autumn Gold, Lakeview, Palo Alto, President	4 - 8	30' x 70'	slow to moderate	Eastern China
Gymnocladus dioicus	Kentucky coffeetree	Fabaceae		3b - 8	40' x 60'	slow to moderate	NY to GA, west to NE and OK
Ilex decidua	possumhaw holly	Aquifoliceae	Red Escort (male)	5 - 9	10' x 15'	slow to moderate	MD to FL, west to KS and TX
Ilex glabra	inkberry holly	Aquifoliceae	Compacta, Densa, Nordic, Cape Cod	5 - 9	8' x 10'	slow, fast from sucker shoots	NY to FL, west to s MO and TX
Ilex vomitoria	yaupon holly	Aquifoliceae		7 - 10	15' x 20'	moderate to fast	VA to FL, west to OK and TX
Maackia amurensis	Amur maackia	Fabaceae		4 - 7	25' x 30'	slow	Manchuria
Maclura pomifera	osage orange	Moraceae	White Shield	4 - 9	30 x 30	fast	AR to LA, west to OK and TX
Metasequoia glyptostroboides	dawn redwood	Taxodiaceae		5 - 8	25' x 80'	fast	China
Nyssa sylvatica	black tupelo	Nyssaceae		4 - 9	25' x 40'	slow to moderate	ME to FL, west to MI and TX
Ostrya vurginiana	hop hornbeam	Betulaceae		3 - 9	25' x 35'	slow	Eastern US
Picea pungens	Colorado spruce	Pinaceae		3 - 7	15' x 50'	slow to moderate	Central and southern Rocky Mountains
Platanus occidentalis	sycamore	Platanaceae		4 - 9	90' x 90'	moderate to fast	ME to FL, west to and TX

Botanical Name	Common Name	Family	Cultivar	Hardiness Zone[1]	Size (H x W)	Growth Rate*	Native Range
Platanus x *acerifolia*	London planetree	Platanaceae	Columbia, Liberty	5 - 8	70' x 100'	moderate	American and Asian hybrid
Quercus acutissima	sawtooth oak	Fagaceae		6 - 9	50' x 50'	moderate	Asia
Quercus bicolor	swamp white oak	Fagaceae		4 - 8	50' x 50'	slow to moderate	ME to NC, west to WI and MO
Quercus macrocarpa	bur oak	Fagaceae		3 - 8	70' x 70'	slow	ME to TN, west to ND and OK
Quercus phellos	willow oak	Fagaceae		5 - 9	35' x 50'	moderate	MD to FL, west to MO and TX
Quercus prinus	chestnut oak	Fagaceae		4 - 8	90' x 90'	moderate	NH to SC, west to IN and AL
Quercus rubra	northern red oak	Fagaceae		3 - 7	60' x 60'	fast	ME to GA, west to MN and AR
Quercus shumardii	shumard oak	Fagaceae		5 - 9	45' x 60'	moderate to fast	NC to FL, west to IN, MO and TX
Quercus texana (syn. *Q. nuttallii*)	Texas red oak	Fagaceae		5 - 9	40' x 50'	fast	KY to Al, west to MO and TX
Robinia pseudoacacia	black locust	Fabaceae		4 - 8	30' x 40'	fast	Eastern US
Sophora japonica	scholar tree	Fabaceae		4 - 7	60' x 60'	moderate to fast	China and Korea
Thuja plicata	giant arborvitae	Cupressaceae		4 - 8	20' x 60'	moderate	Western MT to WA and OR
Tilia cordata	littleleaf linden	Tiliaceae		3b - 7	40' x 60'	moderate	Europe
Tilia tomentosa	silver linden	Tiliaceae		4 - 7	40' x 60'	moderate	Europe, W. Asia
Ulmus americana	American elm	Ulmaceae	Valley Forge, Jefferson, Princeton, New Harmony	3 - 9	40' x 70'	moderate to fast	Eastern US

Botanical Name	Common Name	Family	Cultivar	Hardiness Zone[1]	Size (H x W)	Growth Rate*	Native Range
Ulmus carpinifolia	smoothleaf elm	Ulmaceae	Elsmo, Patriot, Homestead, Prospector	5 - 7	40' x 70'	fast	Europe, N Africa
Zelkova serrata	Japanese zelkova	Ulmaceae		5 - 8	40' x 60'	moderate to fast	Asia

Table 4. Cultural Conditions of Potential Plants for Windbreaks/Buffers of Poultry Production Farms

For best results, always chose a plant species that meets your site conditions. Refer to the Appendix for information on Natural Drainage Classes.

Botanical Name	Common Name	Natural Drainage Class[2]					Light Requirements			Notes
		Excessively Drained	Well Drained	Moderate Well Drained	Somewhat Poorly Drained	Poorly Drained	Sun	Part Shade	Shade	
Acer buergerianum	trident maple		X	X			X	X		Used as a street tree in Japan.
Acer campestre	hedge maple		X	X	X		X	X		'Queen Elizabeth' is faster growing and tolerant of soil compaction.
Acer negundo	boxelder		X	X	X		X	X		'Baron' is a seedless cultivar.
Acer rubrum	red maple		X	X	X	X	X	X		'Brandywine' is a male (seedless) cultivar.
Acer rubrum x *saccharinum*	Freeman maple		X	X	X	X	X	X		
Acer truncatum hybrid	purpleblow maple		X	X	X		X	X		
Alnus rugosa	speckled alder			X	X	X	X			Fixes atmospheric nitrogen, sensitive to heat and drought.
Alnus serrulata	hazel alder			X	X	X	X			Fixes atmospheric nitrogen, sensitive to heat and drought.
Amorpha fruticosa	false indigo		X	X	X		X			pH adaptable, salt tolerant, fruit is banned in CT, fixes atmospheric nitrogen.

Botanical Name	Common Name	Natural Drainage Class[2]					Light Requirements			Notes
		Excessively Drained	Well Drained	Moderate Well Drained	Somewhat Poorly Drained	Poorly Drained	Sun	Part Shade	Shade	
Caragana arborescens	Siberian pea shrub	X		X	X		X	X		Fixes atmospheric nitrogen, very adaptable, salt tolerant.
Celtis laevigata	sugar hackberry		X	X	X	X	X			Tolerant of soil compaction.
Celtis occidentalis	common hackberry	X	X	X	X		X			Salt tolerant.
Cercis canadensis	redbud		X	X			X	X		
Ginkgo biloba	ginkgo		X	X	X		X	X		Use male (fruitless) cultivars.
Gymnocladus dioicus	Kentucky coffeetree			X	X		X			
Ilex decidua	possumhaw holly	X		X	X	X	X	X		*I. opaca* can serve as a pollinator; 'Escort' is a seedless cultivar.
Ilex glabra	inkberry holly			X	X	X	X	X	X	Plants sucker to form thickets.
Ilex vomitoria	yaupon holly	X	X	X	X	X	X	X		Salt tolerant.
Maackia amurensis	Amur maackia			X	X		X	X		Fixes atmospheric nitrogen.
Maclura pomifera	osage orange	X X	X	X	X		X			'White Shield' is thorn free and male (fruitless), sensitive to soil compaction.
Metasequoia glyptostroboides	dawn redwood			X	X	X	X			
Nyssa sylvatica	black tupelo	X	X	X	X	X	X	X		Tap rooted species, transplant in the spring, salt tolerant.

Botanical Name	Common Name	Natural Drainage Class[2]					Light Requirements			Notes
		Excessively Drained	Well Drained	Moderate Well Drained	Somewhat Poorly Drained	Poorly Drained	Sun	Part Shade	Shade	
Ostrya vurginiana	hop hornbeam	X	X	X			X	X		Reestablish slowly after transplanting, soil compaction sensitive.
Picea pungens	Colorado spruce			X	X		X			
Platanus occidentalis	sycamore	X	X	X	X	X	X	X		2, 4-D sensitive.
Platanus x *acerifolia*	London planetree			X	X	X	X	X		
Quercus acutissima	sawtooth oak	X		X	X	X	X	X		Fastest growing oak.
Quercus bicolor	swamp white oak				X	X	X	X		Tolerant of soil compaction.
Quercus macrocarpa	bur oak		X	X	X		X	X		Difficult to transplant due to taproot, very adaptable, sensitive to soil compaction.
Quercus phellos	willow oak		X	X	X		X	X		Transplants well.
Quercus prinus	chestnut oak	X	X	X	X		X	X		Transplants well.
Quercus rubra	northern red oak			X	X		X	X		Transplants well.
Quercus shumardii	shumard oak	X	X	X	X		X			Slow growth after transplanting.
Quercus texana (syn. *Q. nuttallii*)	Texas red oak		X	X	X	X	X			Very good for Southern areas, transplants well.
Robinia pseudoacacia	black locust	X	X	X			X	X		Salt tolerant.
Sophora japonica	scholar tree		X	X	X		X			

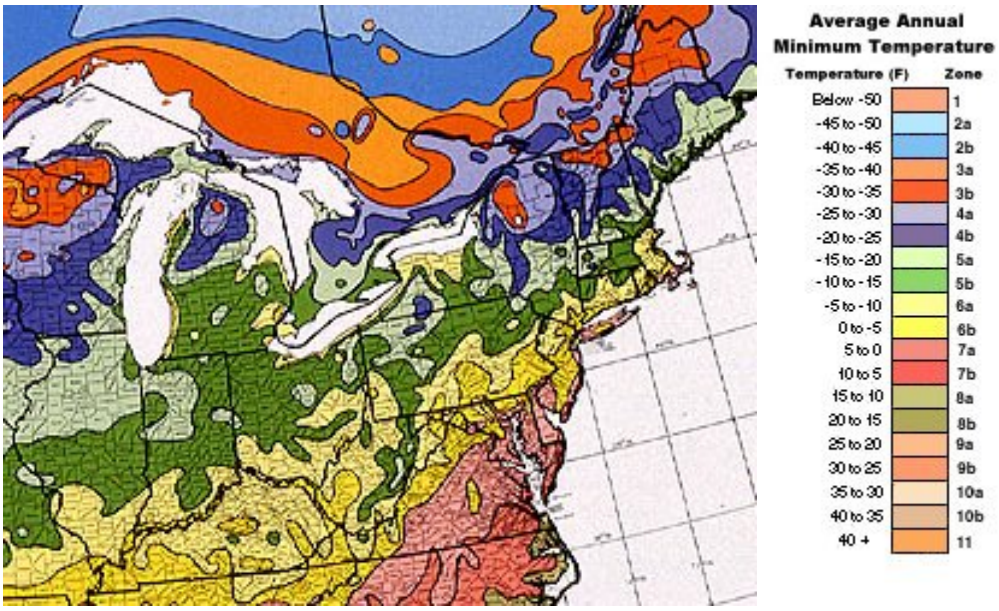
Botanical Name	Common Name	Natural Drainage Class[2]					Light Requirements			Notes
		Excessively Drained	Well Drained	Moderate Well Drained	Somewhat Poorly Drained	Poorly Drained	Sun	Part Shade	Shade	
Thuja plicata	giant arborvitae			X	X	X	X	X		
Tilia cordata	littleleaf linden	X		X			X			
Tilia tomentosa	silver linden		X	X			X			
Ulmus americana	American elm	X	X	X	X		X			Use new Dutch Elm Disease tolerant cultivars.
Ulmus carpinifolia	smoothleaf elm		X	X			X			
Zelkova serrata	Japanese zelkova			X			X			

X

Appendix

1 - USDA Plant Hardiness Zone Map

For more detailed information on the USDA Hardiness Zone Map visit their web site at: http://www.usna.usda.gov/Hardzone/ushzmap.html



2 - Natural Drainage Classes

Refers to the frequency and duration of periods of saturation or partial saturation during soil formation, as opposed to altered drainage, which is commonly the result of artificial drainage or irrigation but may be caused by the sudden deepening of channels or the blocking of drainage outlets. With alteration of the site either by irrigation or by drainage practices, these natural drainage classes may be modified to fit the moisture requirements of the plants. Seven classes of natural soil drainage are recognized. Tables 2 and 4 utilize 5 of these drainage classes.

Excessively drained. Water is removed from the soil very rapidly. Excessively drained soils are commonly very coarse textured, rocky, or shallow. Some are steep. All are free of the mottling related to wetness.

> SOIL MORPHOLOGY: Typically excessively drained soils have bright matrix colors (high chroma and value) in the upper subsoil which gradually fades with depth to the unweathered color of the underlying geologic material. Some excessively drained soils that have developed within recently deposited sediments (flood plain deposits and coastal dunes) lack color development within the subsoil. Excessively drained soils are not mottled within the upper 5 feet. Soil textures are loamy fine sand or coarser below 10 inches.

Somewhat excessively drained. Water is removed from the soil rapidly. Many somewhat excessively drained soils are sandy and rapidly pervious. Some are shallow. Some are so steep

that much of the water they receive is lost as runoff. All are free of the mottling related to wetness.

Well drained. Water is removed from the soil readily, but not rapidly. It is available to plants throughout most of the growing season, and wetness does not inhibit growth of roots for significant periods during most growing seasons. Well drained soils are commonly medium textured. They are mainly free of mottling.

SOIL MORPHOLOGY: Typically well drained soils have bright matrix colors (high chroma and value) in the upper subsoil which gradually fades with depth to the unweathered color of the underlying geologic material. Well drained soils that have developed within recently deposited sediments (floodplain deposits) lack color development. These soils are not mottled within the upper 40 inches. Soil mottling (few, faint and distinct mottles) may be present in some compact glacial till soils above the hardpan layer but are not present in the underlying substratum. Soil textures are typically very fine sand or finer in horizons between 10 to 40 inches.

Moderately well drained. Water is removed from the soil somewhat slowly during some periods. Moderately well drained soils are wet for only a short time during the growing season, but periodically they are wet long enough that most mesophytic crops are affected. They commonly have a slowly pervious layer within or directly below the solum, or periodically receive high rainfall, or both.

SOIL MORPHOLOGY: Typically moderately well drained soils have bright matrix colors (high chroma and value) in the upper subsoil. Moderately well drained soils have distinct or prominent mottles between a depth of 15 and 40 inches below the soil surface.

Somewhat poorly drained. Water is removed slowly enough that the soil is wet for significant periods during the growing season. Wetness markedly restricts the growth of mesophytic crops unless artificial drainage is provided. Somewhat poorly drained soils commonly have a slowly pervious layer, a high water table, additional water from seepage, nearly continuous rainfall, or a combination of these.

Poorly drained. Water is removed so slowly that the soil is saturated periodically during the growing season or remains wet for long periods. Free water is commonly at or near the surface for long enough during the growing season that most mesophytic crops cannot be grown unless the soil is artificially drained. The soil is not continuously saturated in layers directly below plow depth. Poor drainage results from a high water table, a slowly pervious layer within the profile, seepage, nearly continuous rainfall, or a combination of these.

SOIL MORPHOLOGY: Typically poorly drained soils are mottled directly below the A horizon. Depending upon soil profile development and soil textures, matrix colors may vary. Soils that exhibit pronounced Spodic development have an albic horizon which has faint to prominent mottles and is underlain by an ortstein or a spodic horizon which is partially cemented or has iron nodules. The Spodic horizon and material directly underlying the spodic have distinct and prominent mottles. Poorly drained soils with very fine sand or finer textures have matrix colors with chroma of 2 or less within 20 inches of the surface. Poorly drained soils with loamy fine sand or coarser textures have matrix colors with chroma of 3 or less within 12 inches of the surface.

Very poorly drained. Water is removed from the soil so slowly that free water remains at or on the surface during most of the growing season. Unless the soil is artificially drained, most mesophytic crops cannot be grown. Very poorly drained soils are commonly level or depressed and are frequently ponded. Yet, where rainfall is high and nearly continuous, they can have moderate or high slope gradients.

SOIL MORPHOLOGY: Typically very poorly drained soils have organic soil materials that extend from the surface to a depth of 16 inches or more, or either have a histic epipedon or an epipedon that has "n" value of greater than 0.7. These soils are generally gleyed directly below the surface layers.

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